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THESIS

**A MODEL FOR EVALUATING PROPOSALS
FROM MULTIPLE VENDORS WHICH HAVE
DIFFERENT PRICES AND LEAD TIMES**

by

Duane Allen Childress

December, 1995

Principal Advisor:

Alan W. McMasters

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VENDORS WHICH HAVE DIFFERENT PRICES AND LEAD TIMES**

Duane Allen Childress
Lieutenant, Supply Corps, United States Navy
B.S., Virginia Polytechnic Institute and State University, 1983

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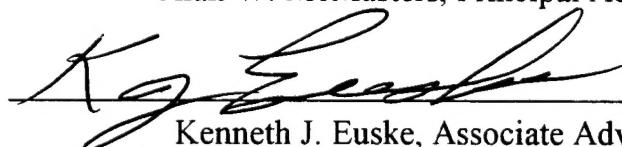
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Duane A. Childress

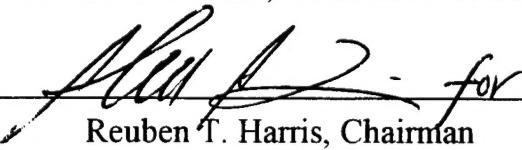
Approved by:

Alan W. McMasters

Alan W. McMasters, Principal Advisor


Kenneth J. Euske

Kenneth J. Euske, Associate Advisor


Reuben T. Harris for
Reuben T. Harris, Chairman
Department of Systems Management

ABSTRACT

This thesis presents a PC-based Best Value model which can be used to evaluate up to three vendor proposals for manufacture of a consumable secondary item. This software is designed to run on EXCEL 5.0 or equivalent applications. Both bid price and production lead time for a given order quantity are considered. The model calculates the minimum expected total annual inventory management costs associated with the item for each vendor. These costs include ordering, holding, backordering, and procurement costs of the item. This thesis provides the mathematical development of the model, illustration of the calculations, and a user's guide for the program. This thesis also compares the current Navy's Flexible Computer-Aided Manufacturing (FCIM-DSS) model with the Best Value model.

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I. INTRODUCTION

A. BACKGROUND

A consumable Best Value model was developed in 1993 for use in comparing various vendors with special emphasis on the production lead time. Prior to that model's development the only model available was the Flexible Computer Integrated Manufacturing (FCIM) Decision Support System (DSS) model which was developed by the Fleet Material Support Office (FMSO). The Best Value model used a time-weighted backorder cost term while the FCIM-DSS model considered only the number of backorders per year. However, both of these inventory models incorporated the savings of shortened lead times into the equation for the expected total annual variable costs associated with inventory management of an item. Reducing procurement lead time is important especially today with declining inventory levels and customer support being measured by the average customer wait time in days. The Best Value model was developed at the request of the Rapid Acquisition of Manufactured Parts (RAMP) Program Office.

Both the FCIM and the Best Value models determined the optimal lot size (Q) and optimal reorder point (R) which minimized the expected total annual variable inventory management costs which included ordering costs, holding costs, backordered or shortage costs, and procurement costs.

The Best Value model was designed to be used on a personal computer having the LOTUS spreadsheet capability. Because this model was highly iterative and required

considerable user involvement in the process, it was not used by the RAMP Program Office or the Navy's Inventory Control Points (ICPs). However, recent discussions with the RAMP Program Office and personnel from the Ships Parts Control Center (SPCC) and the Aviation Supply Office (ASO) about the problems with the Best Value model resulted in their expressing an interest in seeing the model modified to make it more useful and user friendly. In addition, the change from a LOTUS to an EXCEL spreadsheet was requested.

B. OBJECTIVE

This thesis develops the Best Value model into the requested format resulting from the discussions described above. In particular, a spreadsheet program is developed using EXCEL which eliminates the iterative nature of the previous version of the model and makes the program more user friendly. The current model only evaluates one vendor at a time. In this thesis the model is modified to analyze up to three vendors simultaneously, providing output information on all vendors on one spreadsheet printout for easy comparison. Other features which are included in the modification are a method which allows analysis of procurements when expected lead time demand quantities exceed 50 units. It also provides a capability to allow information from the Inventory Control Point Master Data File to be used in computing an optimal probability of a stockout during procurement lead time. As a side issue, the output of the FCIM-DSS model is compared to the Best Value model and will be examined for both derivation differences and sensitivity to procurement lead time changes.

C. SCOPE

This thesis assumes that if expected demand during procurement lead time is less than or equal to 30 units the Poisson probability distribution applies for demand during lead time. When expected demand is greater than 30 units, a Normal approximation to the Poisson distribution is assumed to be applicable. This thesis also assumes the demand distribution is in steady state over time. Finally, the items being considered are assumed to have their lot sizes specified vice requiring the optimal lot size to be determined. This change to the original model is motivated by financial constraints in a declining budgetary environment.

Items examined in this thesis do not include items needed in the interests of national security, special one-time procurements, system phase-outs, and periods of sharply declining demand.

D. METHODOLOGY

The major reference for this thesis is a 1993 thesis by Arthur B. Horsley (Horsley, 1993). His thesis presented the initial version of the Best Value model. That model forms the basis of the model developed in this thesis. A major part of this thesis effort has been the conversion of the Horsley model from the LOTUS spreadsheet model to an EXCEL spreadsheet model which satisfies the current needs of the users. Interviews were held with the user to determine the latter.

E. LIMITATIONS

The program has not been validated or accepted by the Naval Supply Systems Command (NAVSUP). As a consequence, it should be applied to various test situations and

be reviewed at the user level as part of the validation process.

F. PREVIEW

Chapter II is a description of the Best Value model as it was derived in 1993. Chapter III describes the modifications of the Best Value model which were recently requested by the potential users of the model. Within this chapter, illustrative problems are also presented and calculations are performed for both the Poisson and Normal probability distributions for lead time demand. In addition, the procedure using Master Data File (MDF) information to compute target risk is illustrated. Chapter IV presents the User's Manual. Chapter V briefly describes the FCIM-DSS Model and compares it to the Best Value Model. Chapter VI presents a summary of the thesis, conclusions, and recommendations for the model's use.

II. REVIEW OF THE BEST VALUE MODEL

A. BACKGROUND

This chapter will review the Best Value Model as it is currently derived. This review of the derivation for the current model was taken from the 1993 thesis authored by Arthur B. Horsley (Horsley, 1993). The book, "Analysis of Inventory Systems" by G. Hadley and T. M. Whitin (Hadley and Whitin, 1963) was also used extensively in explaining the derivation of this model. The model is a variant of the Navy's Uniform Inventory Control Point (UICP) model used for managing wholesale level consumable item inventories.

The Best Value Model was designed to determine the expected total annual costs of purchasing and carrying a consumable item in inventory that is a candidate for manufacture using the flexible manufacturing cells developed as part of the Rapid Acquisition of Manufactured Parts (RAMP) project. Most of these items are low demand items. The purpose of the model is to determine the optimal order quantity (Q) and reorder point (R) since minimization of the expected total annual costs is being used as the deciding factor between vendors. This process of determining the optimal order quantity and reorder point requires multiple iterations to generate a solution.

The expected total annual costs equation consists of four components. They are ordering costs, holding costs, time-weighted essentially-weighted requisitions backordered costs, and expected annual procurement costs. Ordering costs include any costs associated with establishing the contract and preparing the delivery orders. Holding costs are the costs

associated with maintaining an inventory such as storage, obsolescence, and investment costs. The third component is actually an implied cost item for backorders. The final component is the procurement costs for replenishing the item. The derivation of each of these components will be reviewed in the following sections.

B. ORDERING COST

The ordering costs component of the total annual expected costs equation is expressed as follows:

$$\text{ORDERING COST} = K + A \frac{4D}{Q},$$

where:

K = Annual cost of contract award;

A = Cost of preparing a delivery order;

D = Average quarterly demand forecast; and

Q = lot size.

The K component, annual cost of contract award, includes administrative and advertising costs associated with the contract. Administrative costs include time spent in establishing the contract and analyzing sources. Advertising costs are associated with the advertising that occurs in the Commerce Business Daily in accordance with procurement regulations dealing with competition. This K component is considered to be constant throughout the year because once the contract is established, delivery orders can be made against it at anytime throughout the year. Delivery orders schedule the delivery of items

under the conditions specified in the contract. They are less expensive than initiating a new contract every time an order is needed. They also require a much shorter time to generate an order. Delivery orders are arranged through an already existing contract. If the use of delivery orders is not allowed, then the value of K will be set to zero and the costs of the contract will be combined in the A component since each order will, in fact, be a separate contract.

The next component, A, is the cost of preparing a delivery order. Delivery orders are used to arrange shipment of materials as specified in the contract. This feature provides flexibility in delivery times and quantities.

The D component, quarterly demand, is really a forecast of expected quarterly demand determined from historical data. This is input by the user.

C. HOLDING COSTS

The holding costs of the total annual cost equation are expressed as follows:

$$HOLDING\ COST = I \cdot C \cdot E[OH]$$

where:

I = Holding cost rate (currently .23 for consumables);

C = Cost of the item; and

E[OH] = Expected unit-years of on-hand inventory.

1. Storage Costs

The first component of the holding cost equation is I, the holding cost rate. As

determined by the Department of Defense, it includes storage costs, obsolescence costs, and investment costs. In the Navy, it is currently 23 percent for consumable items and 21 percent for repairable items.

The first component of I is the actual storage costs which account for one percent of the value of the item per year (DODINST 4140.39, 1970). This value is low when compared to industry. Industry's cost is higher due to its ability to better allocate costs to its products. These costs include cost of buildings, insurance, and security. With the government, many of its costs aren't directly traced to its products for a variety of reasons. Many of the buildings are old and have long been capitalized. Many of these buildings are on Naval Stations and receive common services such as security which are not allocated to the inventory. The government also does not have costs such as taxes or insurance.

2. Obsolescence Costs

Obsolescence costs are costs associated with material being stored that is no longer needed in the fleet or material that is no longer useable (such as expired shelf life items). Obsolescence costs account for 10 percent of the 23 percent holding cost rate. Two percent are losses from such things as theft and shrinkage for consumables and zero for repairables (NAVSUP 553, 1991). Obsolescence has gained increased attention in today's shrinking financial climate.

Two options that could help reduce obsolescence costs are reducing the costs associated with contracts. By reducing these costs, smaller lot sizes of items would be ordered more frequently. Another option is to reduce procurement lead time. This would

allow a smaller reorder point resulting in lower inventory levels.

3. Investment Costs

The third and final component of I is a measure of the investment cost or the opportunity cost of money. This component accounts for 10 percent of the holding cost rate. An Office of Management and Budget (OMB) circular is published which approximates the marginal pre-tax rate of return on average investments in the private sector. The current appendix to the OMB circular A-94 cites a seven percent nominal interest rate for a 10-year loan. That amount clearly differs with the 10 percent used in this model (OMB Circular A-94, 1992). However, since the 10 percent figure has long been considered to be the opportunity cost of money, no change has been made in I by the Navy.

These three components storage costs (1 percent), obsolescence costs (10 percent), pilferage and shrinkage (2 percent), and opportunity costs (10 percent) combine to give us the 23 percent I value.

4. Expected Unit-Years On-Hand Inventory

The final component of the holding cost equation is E[OH] which represents the expected unit years of on-hand inventory. This value can be determined from the definition of inventory position (IP). Inventory position is equal to the number of units on-hand (OH) plus the number of units on-order (OO) minus the number of units backordered (BO). In equation form, it is:

$$IP = OH + OO - BO.$$

The expected value of the inventory position equation can be then be written as:

$$E[IP] = E[OH] + E[OO] - E[BO].$$

The equation can now be manipulated to give us the expected on-hand inventory:

$$E[OH] = E[IP] - E[OO] + E[BO].$$

To gain a better understanding of this model, the equations for the expected inventory position, expected on-order inventory, and expected backorder inventory will each be examined separately.

a. Expected Inventory Position

As explained in Hadley and Whitin (page 181) let R be the reorder point in terms of inventory position. After an order is placed for a lot size Q , the inventory position becomes $R+Q$. This results in an inventory position between $R+1$ and $R+Q$. The model is only in the state R for an infinitely small amount of time because, at the instant when R is reached, another order is placed. Thus, inventory position immediately becomes $R+Q$. Note that this may not be true in real world terms because financial constraints may preclude placing an order for more items or the process may not truly a continuous review, which is the case for the model used by the Navy's Inventory Control Points (ICP).

Expected inventory position can be written as:

$$E[IP] = \sum_{x=R+1}^{R+Q} xp(x),$$

where $p(x)$ is the probability that the inventory position is $R+x$. Hadley and Whitin show that $p(x) = \frac{1}{Q}$ for all x , $R+1 \leq x \leq R+Q$, under the assumption that demand is Poisson distributed. Thus, the following formula results:

$$E[IP] = \frac{1}{Q} \sum_{x=1}^Q (R + x).$$

This can be simplified to :

$$\begin{aligned} E[IP] &= \frac{1}{Q} \left[\sum_{x=1}^Q R + \sum_{x=1}^Q x \right]; \\ &= \frac{1}{Q} [RQ + \frac{Q(Q+1)}{2}]; \\ &= R + \frac{Q}{2} + \frac{1}{2}. \end{aligned}$$

b. Expected On-order Inventory

The value of expected on-order inventory is equal to mean lead time demand; that is, where mean lead time demand is represented by $E[OO] = \mu$ (mu). Hadley and Whitin (page 187) argue that this true as follows,

The fact that the expected amount on order should be the mean lead time demand can be seen intuitively as follows. Imagine that orders flow into one end of a pipeline and that procurements flow out the other end. Since all demands are ultimately met, the mean rate of flow of units ordered into the pipeline must be λ . Since an order remains in the pipeline for a time τ , the

expected number in the pipeline should be $\lambda\tau = \mu$.

Note that Hadley and Whitin used λ as the mean demand rate and τ as the procurement lead time. However, the Navy's ICP's use D as the mean demand rate and PCLT as the procurement lead time. Throughout this thesis LT will be used to represent procurement lead time.

c. Expected Backordered Inventory

The expected backordered unit-years of inventory is a function of the order quantity (Q) and reorder point (R). It can be written as:

$$E[BO] = B(Q,R).$$

From Hadley and Whitin (page 184) the formula for determining expected unit-years of backordered inventory when demand is Poisson distributed is:

$$B(Q,R) = \frac{1}{Q} \left[\sum_{u=R+1}^{\infty} (u-R-1)P(u;\mu) - \sum_{u=R+Q+1}^{\infty} (u-R-Q-1)P(u;\mu) \right],$$

where $P(u;\mu)$ is the probability that lead time demand is greater than or equal to u , given that mean lead time demand is μ . A simplification of this formula which results from the properties of the Poisson demand distribution is then derived in Hadley and Whitin (page 185). It begins with the definition of $\beta(v)$.

$$\beta(v) = \sum_{u=v+1}^{\infty} (u-v-1)P(u;\mu);$$

which can be reduced to

$$\beta(v) = \frac{\mu^2}{2} P(v-1; \mu) - \mu v P(v; \mu) + \frac{v(v+1)}{2} P(v+1; \mu).$$

This allows the expected unit-years of backordered inventory to be written as:

$$B(Q, R) = \frac{1}{Q} [\beta(R) - \beta(R + Q)].$$

5. Expected Holding Costs Formula

The formula for holding costs can be stated first as

$$HOLDING\ COSTS = IC[E(IP) - E(OO) + E(BO)].$$

Then, substitution of the formulas for the various components of the right-hand side of the equation results in

$$HOLDING\ COSTS = IC[R + \frac{Q}{2} + \frac{1}{2} - \mu + B(Q, R)].$$

D. TIME-WEIGHTED, ESSENTIALLY-WEIGHTED, REQUISITIONS BACKORDERED

This component of the expected total annual costs equation is the cost associated with the expected unit-years of requisitions backordered. These shortage or backorder costs are described in NAVSUP 553 on page 35 as the

...actual cost of not having an item available when the customer needs it. In the military environment it is extremely difficult (and politically infeasible) to obtain

dollar values for the costs of shortage, as it may involve placing a dollar value on the loss of a life. DOD Instruction 4140.39 permits the military to use implied shortage costs as a management parameter based on the funds available for investment in inventories and in the management of these inventories.

Requisition-years are used because the objective as stated in DODINST 4140.39 is "To minimize the total of variable order and holding costs subject to a constraint on time-weighted, essentially-weighted requisitions short."

When the Lagrangian function of the DOD objective function and constraint is formed to determine optimal Q and R, the Lagrange multiplier associated with the constraint plays the role of the cost of one requisition short for one year. Thus, the Lagrange multiplier can be viewed as an implied cost of a backorder.

The UICP formula for the expected annual time-weighted, essentially-weighted requisitions short cost is:

$$\text{BACKORDER COST} = \frac{\lambda E}{S} B(Q, R);$$

where:

λ = The implied shortage cost per requisition backordered per year;

E = An essentility factor between 0 and 1, normally 1.0;

S = The average customer requisition size (i.e., the average number of units of an item requisitioned by a customer);

B(Q, R) = The expected unit years of inventory backordered.

The value of λ is determined annually by the Navy's ICPs and is provided in the

Master Data File (MDF).

Horsley's thesis provided an alternative way for determining λ . It was based on the following formula

$$\frac{SIC}{SIC + \lambda E} = RISK,$$

which is the ICP's equation for determining the optimal reorder point. RISK is the probability of a stockout during procurement lead time. If a λ value is not known the user may still be able to set a target value for RISK. When a target risk is provided, the following formula can be used to determine the implied value of λ . It is obtained by solving the RISK formula above for λ . The result is

$$\lambda = \frac{SIC}{E} \left(\frac{1}{RISK} - 1 \right).$$

E. EXPECTED ANNUAL PROCUREMENT COSTS

The final component of the expected total annual costs are the procurement costs. They are given by the following formula:

$$ANNUAL\ PROCUREMENT\ COSTS = 4DC;$$

where:

D = expected quarterly demand rate; and

C = unit price.

F. EXPECTED TOTAL ANNUAL COSTS EQUATION

When all of the expected costs components are combined, the equation for the expected total annual costs is

$$TAC = K + A4\frac{D}{Q} + IC[R + \frac{Q}{2} + \frac{1}{2} - \mu + B(Q, R)] + \frac{\lambda E}{S}B(Q, R) + 4DC$$

III. MODIFICATIONS TO THE BEST VALUE MODEL

A. INTRODUCTION

This chapter will discuss problems noted with the current Best Value Model and the modifications recently requested to make the program more user friendly. The 1993 model dealt primarily with finding the optimal Q (lot size) value and optimal R (reorder point).

In August 1995 a conference call was held with the Aviation Supply Office (ASO), the Rapid Acquisition of Manufactured Parts (RAMP) Program Office, and the Ships Parts Control Center (SPCC) to get their input and suggestions about the Best Value Model. The first suggestion was to change the spreadsheet to allow the comparison of three vendors on one spreadsheet output page. The 1993 Horsley model produces a separate output page for each vendor.

The second suggestion was to reduce the iterative nature of the 1993 program. The 1993 program first determines the optimal R (reorder point) and then determines the optimal Q (lot size). To accomplish the second part various order quantities (Q) must be entered into the program and the associated total annual expected costs calculated. The users stated that with most of the RAMP type of orders the lot size (Q) has already been determined. Thus, optimal lot size does not need to be calculated.

The third suggestion was to provide a method to handle expected demand quantities during lead time of greater than 50 units. The current model can handle expected demand quantities of 50 units or less with the Poisson distribution. To handle expected demand

quantities greater than 50 units, the Normal distribution will have to be used.

The fourth and final suggestion was to provide a way for information from the Master Data File (MDF) of the Navy's Inventory Control Points (ICP) to be incorporated. For example, the 1993 model uses a target risk which is set by the user. The new model will include an option to incorporate information from the MDF in the determination of optimal risk.

In summary, a new model is needed which is able to compare the total annual expected costs of three vendors for a given order quantity Q on one spreadsheet. It should be less iterative than the 1993 model, be able to handle expected demand quantities during procurement lead time of over 30 units, and provide a means to incorporate shortage cost information from the MDF into the decision making process.

B. NORMAL DISTRIBUTION

As mentioned above, the 1993 model used the Poisson distribution for expected demand quantities during procurement lead time of less than or equal to 50 units. Any higher expected demands produced error statements. Fortunately, as the expected demand quantities during procurement lead time increase, the Poisson probabilities can be approximated by a Normal distribution. Indeed, as the expected quantity demanded during procurement lead time approaches infinity, the Poisson distribution approaches a Normal distribution with mean μ and $\sigma^2 = \mu$ (Hadley and Whitin, 1963). An examination of the Poisson and Normal distributions as the expected demand increased suggested that lowering of the maximum expected demand for the Poisson from 50 to 30 units and using the Normal for expected

demands greater than 30 would work quite well as an approximation. Therefore, on expected demand of 30 units was used as the "break point" between the two distributions in this modification and no upper limits were imposed on the mean of the Normal distribution.

When determining expected total annual costs assuming the Normal distribution, the ordering costs and procurement costs formulas remained the same as the Poisson distribution. The only changes that will occur are in the holding costs and the backorder costs. The $\frac{1}{2}$ in the holding cost term is dropped and the $\beta(v)$ formula for determining $B(Q, R)$ is different. As stated in Hadley and Whitley (pages 193-194), the following equations apply for the expected unit-years backordered in a Normal distribution:

$$B(Q, R) = \frac{1}{Q} [\beta(R) - \beta(R+Q)];$$

where now

$$\beta(v) = \frac{1}{2} [\sigma^2 + (v-\mu)^2] \Phi\left(\frac{v-\mu}{\sigma}\right) - \frac{\sigma}{2} (v-\mu) \phi\left(\frac{v-\mu}{\sigma}\right).$$

To determine "z" values for the Normal distribution when the risk is known the following approximation formula, taken from the "Handbook of Mathematical Functions", page 932, of the National Bureau of Standards of Applied Mathematics (National Bureau of Standards of Applied Mathematics Series 55, 1964), can be used.

$$z = w - [(2.525517 + .802853w + .010328w^2) / (1 + 1.432788w + .189269w^2 + .001308w^3)];$$

where:

$$w = \sqrt{-2\ln(risk)}.$$

After z has been determined, the reorder point (R) can be determined by using the following formula:

$$R = DLT + z\sigma_{LTD}$$

where:

D = quarterly demand;

LT = procurement lead time in quarters;

z = normal deviate value; and

σ_{LTD} = standard deviation of lead time demand.

Since, as noted above, $\sigma^2 = \mu$, it follows that $\sigma_{LTD} = \sqrt{DLT}$.

The $\Phi(z)$ value, as described in Hadley and Whitin (page 444), is given by the following formula

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}$$

The $\Phi(y)$ represents the complementary cumulative distribution function for the Normal. It can be approximated by the following formula which is also provided in the "Handbook of Mathematical Functions" of the National Bureau of Standards of Applied

Mathematics.

$$\Phi(y) = \phi(y) [b_1Z - b_2Z^2 + b_3Z^3];$$

where:

$$Z = \frac{1}{1+py},$$

$$b_1 = .4361836,$$

$$b_2 = .12011676,$$

$$b_3 = .9372980, \text{ and}$$

$$p = .33267.$$

C. USING INFORMATION FROM THE MASTER DATA FILE

Information can be taken from the Master Data File (MDF) to determine target RISK instead of the user entering source desired target risk value. The necessary information is periodically printed out for the inventory managers. The information is provided for each four-digit "cog" being managed by the ICP. Using this ICP "cog sheet", minimum risk, maximum risk, and shortage cost can be determined. With this information and the forecasted expected number of demands, D, and requisitions per quarter, W, the UICP model's optimal RISK can be determined using the following equation:

$$RISK = \frac{SIC}{SIC + \lambda E};$$

where:

S=average requisition size;

I= holding cost rate;

C=unit cost of the item;

λ =shortage cost;

E= essentiality code.

Note that W and D for a given item can be taken from the Consolidated Stock Status Report (CSSR). The S value can then be computed from the formula:

$$S = \frac{D}{W}$$

After this RISK value is calculated, it must be checked to see that it is within the ICP's minimum and maximum risk values. If the calculated RISK is below the minimum risk, the minimum risk value will be used. If the calculated RISK is above the maximum risk, the maximum risk will be used. If the calculated RISK falls within the range of the minimum and maximum risk, the calculated RISK will be used. The resulting risk value will then be used as the target risk in the rest of the computations.

D. ILLUSTRATIVE PROBLEMS

1. Poisson Distribution Example Problem

The following example problem demonstrates how the Poisson distribution is used to solve for expected lead time demand quantities of less than or equal to 30 units. In this example a value of target risk is specified, not computed. The following information

applies to the problem:

Demand (D) = 1 unit per quarter

Delivery order costs (A) = \$50

Procurement Lead time (LT) = 4 quarters

Cost of the item (C) = \$400 per unit

Cost to establish contract (K) = \$200

Target risk = .25

Requisition Frequency (W) = 1 requisition/qtr.

Order quantity (Q) = 4 units

From this information, the expected lead time demand quantity (D_{LT}) can be determined by multiplying the procurement lead time in quarters by the expected demand per quarter; namely, $D \times LT$. The product in this example is 4.0, which will also be denoted as μ for convenience. The Poisson distribution with a μ of 4.0 is given in Table 1. In addition, the table provides the probability that lead time demand (LTD) is greater than or equal to the reorder point R plus one unit, which is the risk for a given R value (i.e., the probability that demand during lead time will exceed the reorder point).

X	P(LTD = X)	P(LTD ≥ R + 1)
0	.0183	.9817
1	.0733	.9084
2	.1465	.7619
3	.1954	.5665
4	.1954	.3711
5	.1563	.2148
6	.1042	.1106
7	.0595	.0511
8	.0298	.0213
9	.0132	.0081
10	.0053	.0028

Table 1. The Poisson distribution and risk for a given R when $\mu=4.0$.

Table 1 can be used to determine the reorder point R. This is done by choosing the smallest X value such that the value in the P(LTD ≥ R+1) column is less than the target risk of .25. The result is that R = 5.

To determine the β values, remember that the formula for $\beta(v)$ is as follows:

$$\beta(v) = \frac{\mu^2}{2} P(v-1; \mu) - \mu v P(v; \mu) + \frac{v(v+1)}{2} P(v+1; \mu);$$

where $P(v; \mu) = P(LTD \geq v)$.

Using the above formula with R replacing v, the value of $\beta(R)$ is computed as follows:

$$\beta(R) = \frac{4^2}{2}(.5665) - (4)(5)(.3711) + \frac{5(6)}{2}(.2148)$$

$$\beta(R) = .332.$$

The value of $\beta(R+Q)$ is then computed using the same formulas. The computation is as follows for $R+Q = 5+4 = 9$.

$$\beta(R+Q) = \frac{4^2}{2}(.0511) - 4(9)(.0213) + \frac{9(10)}{2}(.0081)$$

$$\beta(R+Q) = .0065.$$

The value of $B(Q,R)$ can now be determined from the following formula as described in the previous chapter:

$$B(Q,R) = \frac{1}{Q}[\beta(R) - \beta(R+Q)].$$

For this example the equation is:

$$B(Q,R) = \frac{1}{4}[.332 - .0065]$$

The expected onhand inventory, $E[OH]$, can now be computed as follows:

$$B(Q,R) = .0814.$$

$$E[OH] = R + \frac{Q}{2} + \frac{1}{2} - \mu + B(Q,R)$$

$$E[OH] = 5 + 2 + \frac{1}{2} - 4 + .0814$$

$$E[OH] = 3.5814.$$

The following equation is next used to determine the implied backorder costs:

$$\lambda = \frac{SIC}{E} \left(\frac{1}{RISK} - 1 \right)$$

where RISK is the target risk specified. First, however, S must be computed.

$$S = \frac{D}{W} = \frac{1}{1} = 1.$$

Then, substitution of the S and target risk values into the above formula for λ gives

$$\lambda = \frac{(1)(.23)(400)}{1} \left(\frac{1}{.25} - 1 \right) = \$276.00.$$

This value of λ is used to determine the implied expected annual time-weighted requisitions backorder costs using the following formula from Chapter II.

$$BACKORDER COSTS = \frac{\lambda E}{S} B(Q, R)$$

$$BACKORDER COSTS = \frac{(276)(1)}{(1)} .0814 = \$22.47.$$

Ordering costs are determined from the Chapter II formula,

$$\begin{aligned} \text{ORDERING COSTS} &= K + A4 \frac{D}{Q} \\ \text{ORDERING COSTS} &= 200 + 50 \left(\frac{4(1)}{4} \right) = \$250. \end{aligned}$$

Next, for the expected annual holding costs,

$$\begin{aligned} \text{HOLDING COSTS} &= IC \left[R + \frac{Q}{2} + \frac{1}{2} - \mu + B(Q, R) \right] \\ \text{HOLDING COSTS} &= (.23)(400) \left[5 + \frac{4}{2} + \frac{1}{2} - 4 + .0814 \right] = \$329.49. \end{aligned}$$

Finally, the expected annual procurement costs are $4DC$ or $(4)(1)(400) = \$1600.00$.

The total expected annual costs can now be calculated. As described in Chapter II, the total expected annual cost equation is as follows:

$$TAC = K + A \frac{4D}{Q} + IC \left[R + \frac{Q}{2} + \frac{1}{2} - \mu + B(Q, R) \right] + \frac{\lambda E}{S} B(Q, R) + 4DC$$

$$TAC = \$250.00 + \$329.49 + \$22.47 + \$1600.00 = \$2201.96.$$

2. Normal Distribution Example Problem

This problem will require the use of the Normal distribution because of an expected demand lead time value greater than 30 units. In this problem the following

parameters apply:

Demand (D) = 10 units per quarter

Delivery order costs(A) = \$50

Procurement Lead time (LT) = 4 quarters

Cost of the item (C) = \$400 per unit

Cost to establish contract (K) = \$200

Target risk = .25

Essentiality (E) = 1

Avg. customer requisition size (S) = 1

Order quantity (Q) = 4

In this case, expected demand during lead time (μ) is $D_{LT} = 10(4) = 40$ items.

Since this value is above 30 items the Normal distribution is used. The standard deviation of lead time demand is $\sigma_{LTD} = \sqrt{\mu} = \sqrt{40} = 6.32$. Note that this formula for σ_{LTD} assumes the Normal to be a limiting case of the Poisson.

The z value for R is determined by using the formula found on page 932 in the "Handbook of Mathematical Functions" which is:

$$z = w - [(2.525517 + .802853w + .010328w^2) / (1 + 1.432788w + .189269w^2 + .001308w^3)].$$

The w value in this example is 1.6651 (i.e., $w = \sqrt{-2\ln(.25)}$) which results in a z value of .6715. Knowing z, $\phi(z)$ is next computed

$$\phi(.6715) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(.6715)^2} = .3184.$$

It will be needed later for the B(Q,R) equation.

The reorder point can be determined from the equation, $R = D_{LT} + z\sigma_{LTD}$, which

results in $R = 40 + (.6715)(6.32) = 44.24$. The $R+Q$ value results in $R+Q = 44.24 + 4 = 48.24$.

The z value for $R+Q$ is needed for the $B(Q, R)$ equation also and is determined as follows:

$$z = \frac{R+Q-D_{LT}}{\sigma_{LTD}} = \frac{48.29-40}{6.32} = 1.312.$$

Once this z is known, $\phi(z)$ can be computed.

$$\phi(1.312) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(1.312)^2} = .1687.$$

The last component needed to calculate $\beta(R)$ and $\beta(R+Q)$ is the complementary cumulative distribution function for the Normal distribution. It is computed using the approximation for $\Phi(y)$, given earlier. First, the y value must be computed

$$y = \frac{R-D_{LT}}{\sigma_{LTD}} = \frac{4.29}{6.32} = .6788.$$

The value for $\Phi(y)$ can now be determined from the earlier formula:

$$\begin{aligned}\Phi(.6788) &= \phi(.6715)[b_1Z - b_2Z^2 + b_3Z^3] \\ &= .3184[.7881] \\ &= .25.\end{aligned}$$

This value is also the target risk value. That is not a coincidence since $P(LTD > R) \equiv$

$$\Phi\left(\frac{R - D_{LT}}{\sigma_{LTD}}\right).$$

The $\beta(R)$ value can be determined as follows:

$$\begin{aligned}\beta(R) &= \frac{1}{2}[\sigma_{LTD}^2 + (R - D_{LT})^2]\Phi\left(\frac{R - D_{LT}}{\sigma_{LTD}}\right) - \frac{\sigma_{LTD}(R - D_{LT})\phi\left(\frac{R - D_{LT}}{\sigma_{LTD}}\right)}{2} \\ \beta(R) &= \frac{1}{2}[40 + (4.29)^2](.25) - \frac{6.32}{2}(4.29)(.3184) \\ &= 2.981.\end{aligned}$$

The $\beta(R+Q)$ value is determined next. The first step is the argument y in $\Phi(y)$.

$$y = \frac{R + Q - D_{LT}}{\sigma_{LTD}} = \frac{48.24 - 40}{6.32} = 1.304.$$

The value of $\Phi(y)$ can now be determined from the earlier formula:

$$\begin{aligned}\Phi(1.304) &= \phi(1.312)[b_1Z - b_2Z^2 + b_3Z^3] \\ &= .1687(.5638) \\ &= .0951.\end{aligned}$$

The $\beta(R+Q)$ value is then

$$\begin{aligned}\beta(R+Q) &= \frac{1}{2}[40 + (8.29)^2](.0951) - \frac{6.32}{2}(8.29)(.1687) \\ &= .7505.\end{aligned}$$

Finally, the value of $B(Q, R)$ is

$$\begin{aligned}
 B(Q,R) &= \frac{1}{Q}(\beta(R) - \beta(R+Q)) \\
 &= \frac{1}{4}(2.981 - .7505) \\
 &= 5577
 \end{aligned}$$

Ordering costs are determined from the formula, ORDERING COSTS =

$K + A_4 \frac{D}{Q}$. From this example the ordering costs are determined to be: $200 + (50)(4) \frac{10}{4} = \700 .

Holding costs are equal to $IC[R + \frac{Q}{2} - B(Q,R)]$ which gives

$$\begin{aligned}
 HOLDING\ COSTS &= (.23)(400)[44.24 + \frac{4}{2} - .5577] \\
 &= \$4202.77
 \end{aligned}$$

To determine the backorder costs, λ must first be determined. In this case, the target risk is again specified so the formula for λ given earlier in this chapter again applies.

$$\lambda = \frac{(1)(.23)(400)}{1} \left(\frac{1}{25} - 1 \right) = \$276.00$$

The expected annual backorder costs can now be determined.

$$BACKORDER\ COSTS = \frac{\lambda E}{S} B(Q,R) = \frac{(276)(1)}{(1)} .5577 = \$153.93$$

Finally, annual procurement costs are $4DC$ or $(4)(10)(400) = \$16000.00$. Therefore, the expected total annual costs for this item are

TAC = 700+3858.69+153.93+16000= \$20712.62.

3. Risk Determined From the Master Data File

Target risk can be determined by information provided from the Master Data File.

To illustrate the process assume the following information is provided from the MDF:

Quarterly demand (D) = 5 units Cost of an item (C) = \$200 per unit

Shortage cost (λ) = \$1000

Cost of an item (C) = \$200 per unit

Shortage cost (λ) = \$1000

Essentiality code (E) = 1

Maximum risk = .35

Minimum risk = 10

Expected number of requisitions per quarter (W) = 3.33

From the information provided, S can be determined from $S = \frac{D}{W} = \frac{5}{3.33} = 1.5$,

and target risk can be calculated as follows:

$$RISK = \frac{SIC}{SIC + \lambda E} = \frac{(1.5)(.23)(200)}{(1.5)(.23)(200) + (1000)(1)} = .065.$$

The Master Data File (MDF) gives a minimum risk of .1 and a maximum risk value of .35. The calculated risk is .065 which is below the minimum risk which is .1; therefore, the target risk for this problem is constrained to .1. As mentioned earlier, if the calculated risk had been within the bounds of the minimum and maximum risk, the calculated risk would have been used as target risk. If the calculated risk had been above the bound as set by the maximum risk, the maximum risk would have been used as target risk.

IV. USER'S MANUAL

A. INTRODUCTION

This chapter will explain how to use of the EXCEL spreadsheet model and the various required inputs and the nature of the output document. Each input will be explained and the output results will be shown.

The spreadsheet is divided into three separate sections; an input section, a calculation section, and an output section. The calculation section will be hidden by using the column hide feature of EXCEL. If the logic used in the calculation section wants to be viewed, the unhide feature can be used to examine the calculations. This feature may be useful if this program is converted to a more powerful language or is put into a menu driven program.

Up to three vendors bidding on the same item can be placed on the same output spreadsheet. This allows for the quick comparison of all vendors. The output also includes all input data to allow the user to check the validity of all inputs. This feature allows the user a "big picture" view of all the information.

B. BID EVALUATION WORKSHEET

Preparation of the Bid Evaluation Worksheet is the first step in running the Best Value model. Its layout is similar to the input section with a few exceptions. This was done to reduce the possibility of input mistakes by the user. The Bid Evaluation Worksheet is contained in Appendix A.

The Bid Evaluation Worksheet first asks for item nomenclature, item National Item Identification Number (NIIN), forecasted quarterly demand (in units per quarters), contract award price, delivery order cost, essentiality code, average requisition size (units/requisition) and order quantity needed. At the bottom of the sheet there is a section to enter risk calculation information. This information includes the four-digit item cog, minimum risk, maximum risk, and shortage cost. This information will be needed if a target risk is not given and the target risk must be determined from MDF information.

Item nomenclature and NIIN are self explanatory. This information is used to identify the item that is being bid upon. Quarterly demand (D) is the forecasted amount of the item expected to be demanded in a quarter. This information can be taken from the Consolidated Stock Status Report (CSSR). Contract award price (K) is the cost associated with awarding the contract. Delivery order costs (A) are the costs associated with establishing delivery orders on the contract. If delivery orders are not possible or of interest, the value for the contract award price is zero and the value for the contract award price is entered as the delivery order cost. The contract award price and delivery order cost must be determined locally. An essentiality code (E) can also be entered; its default value should be 1.0. The next entry is the average requisition size (S). The average requisition size (S) is not available on the Consolidated Stock Status Report (CSSR) so it must be calculated from other information on the CSSR; namely, the forecasted quarterly demand (D) and the forecasted number of requisitions per quarter (W). The value of S is obtained by dividing D by W. Finally, the order quantity must be entered. Its value is

typically known ahead of time before the request for bids is sent out to potential vendors.

Target risk Company 1, target risk Company 2, and target risk Company 3 can be also be entered directly if known. If the risk is to be determined from the MDF information then that information, item four-digit cog, minimum risk, maximum risk, and shortage cost will need to be entered at the bottom of the Bid Evaluation Worksheet for use in the spreadsheet to determine target risk for each company. The shortage cost and minimum and maximum risk values are available from the ICP's cog data sheet. An example of that sheet is provided in Appendix D.

The final information needed by the worksheet are the bid unit costs and procurement lead times. Procurement lead time is the sum of the ICP's known administrative lead time and the vendor's bid production lead time. The latter must be in quarters so if a bid lead time is in days then it needs to be divided by 91, if it is in weeks then it needs to be divided by 13.

After completing the Bid Evaluation Worksheet, the user is ready to start the program. To start the program enter the EXCEL program and open the file entitled BVM from the disk. The input section will appear on the screen. A sample of the input section is provided in Appendix B.

C. INPUT SECTION

The input section contains three sections which include general data on the requested item, specific data on the various vendors bidding on the contract, and a calculated risk section to be used if risk is to be computed using MDF data. The input

section allows for an initial comparison of three vendors.

The first section, general data, requests the following data which include item nomenclature, item NIIN, forecasted quarterly demand, contract award price, delivery order cost, essentiality code, average units/requisition, order quantity needed, target risk Company 1, target risk Company 2, and target risk Company 3. This information should be entered directly from the Bid Evaluation Worksheet.

If MDF information is used to determine target risk, the calculated risk section will be used. This is the only iterative part of the program because the user has to choose between minimum risk, maximum risk, and calculated risk. Additional information required for this section include item cog, minimum risk, maximum risk, and shortage cost. The value of the calculated risk will be calculated automatically by the program as soon as all values have been entered. To use the calculated risk as target risk, it must be within the range of minimum and maximum risk. If it is, the user enters it into the "Target Risk Company" cell. If the calculated risk is below the minimum risk, then the user must enter minimum risk value as target risk. If the calculated risk is above the maximum risk, then the user must enter the maximum risk value as target risk.

After the target risk has been determined for each company, the source of the risk calculation for each company can be entered as "target risk" or "MDF" by the user. This will allow management the opportunity to review the source of the risk factors.

Finally, to complete the input section of the spreadsheet, the user should enter the individual company names, bid item unit cost and bid procurement lead time. Remember

that procurement lead time is the sum of the ICP's administrative lead time and vendor's bid production lead time.

D. CALCULATION SECTION

Using the input information, the EXCEL spreadsheet program will automatically compute the expected annual ordering costs, holding costs, backorder costs, procurement costs, and total annual costs for each individual company. For each company the spreadsheet will then provide information as to how the target risk was determined. The "Risk calculated from block" will read "target risk" if the target risk value is assigned by the user and "MDF" if MDF information was used to determine target risk. This is a repeat of the information input at the top of the sheet just below the calculated risk section.

The calculation section is located in hidden columns. The "hide" function was used to prevent the calculations from needlessly being viewed by the user. This was done to protect the integrity of the calculations by eliminating the possibility of a user inadvertently placing a false or inappropriate value in one of the cells. It was also done to reduce the confusion on the part of the user.

In the Poisson distribution section of the calculation section of the spreadsheet a Poisson distribution table has to be constructed, as was done in the illustrative example in Chapter III, using the Poisson function available in EXCEL 5.0 if expected lead time demand is 30 units or less. Then the VLOOKUP function is used to identify the various probabilities needed in the computation of the reorder points and time-weighted

backorders. This function automatically allows the transfer of the probability values into the expected cost equations.

The Normal distribution section of the spreadsheet is constructed similarly to the Poisson distribution but a table is not needed since approximate equations are available from the National Bureau of Standards. All needed values are therefore easily calculated from the input data and are then automatically combined in equations for the appropriate output values. Chapter III gave examples of the calculations performed when the Normal distribution is appropriate.

E. OUTPUT SECTION

The output section includes each company name, bid item unit cost and procurement lead time. It also includes the values of the expected costs of the components included in the expected total annual variable costs. Finally, the output section repeats the input data. This is done to ensure the integrity of the input data. This feature also allows the user to review all data on one spreadsheet. A sample of the output data spreadsheet is presented in Appendix C.

The output section is designed to give managers a single spreadsheet review of the data which was used to determine various expected annual total costs and hence the best value bid. The company with the smallest total annual costs is the potential winner. In Appendix C, the winner would be Company 3, Gap Machine, because it has the lowest total annual costs.

To produce a printout of the input section, the user would produce sheet 1 on the

print menu after viewing it on the computer screen. To produce a printout of the output section, the user would produce sheet 2 on the print menu. When the user is ready to shut down the program, go to "File" and "Close". Results can be saved if desired by using the "Save" function and then closing the file.

V. COMPARISON OF THE FCIM AND BEST VALUE MODELS

A. MODEL FORMULATION DIFFERENCES

The Flexible Computer Integrated Manufacturing (FCIM) model was developed by the Fleet Material Support Office (FMSO) for use in evaluating vendor bids having both unit price and production lead times which differ from the values in the MDF. The goal was to be able to determine what savings if any in "relevant annual costs" the vendor's bid would provide over that of continuing with a current vendor whose unit price and production lead time correspond to the MDF values.

In reviewing the FCIM User's Manual several aspects of the model appear inconsistent with the UICP model used by the Navy's ICPs in managing wholesale level inventories and hence the Best Value model presented earlier in this thesis. Perhaps the most significant inconsistency is that the shortage cost term in the expected total annual variable costs equation considers only the expected number of backorders per year instead of the expected time-weighted requisitions short per year. In addition, there is no time-weighted backorders term in the holding costs formula. This change results in a different RISK formula from the UICP consumable model. In fact, the RISK formula used in FCIM cannot be derived by the calculus using the FCIM Annual Total Variable Costs (ATVC) equation given in Appendix B of the FCIM User's Manual. That equation is:

$$ATVC = 4DC + \frac{4AD}{Q} + IC\left(\frac{Q}{2} + R - D_{LT}\right) + \lambda \frac{4D}{Q} E(LTD > R).$$

where $E(LTD>R)$ is the expected number of backorders in an order cycle. The derivative of ATVC with respect to R , when set to zero, gives:

$$P(LTD>R) = \frac{QIC}{4D\lambda} = RISK.$$

If, instead, ATVC had as the last term the following formula,

$$\lambda \frac{4W}{Q} E(LTD>R);$$

then the calculus gives

$$P(LTD>R) = \frac{QIC}{4W\lambda} = RISK.$$

This corresponds to the formula given in the FCIM User's Manual on page B-2. The problem with this shortage cost term is that the number of orders placed per year is not $\frac{4W}{Q}$ unless requisitions are always for one unit (i.e., $W=D$). Thus, the model used to derive the RISK formula and the model used to determine the total annual variable costs are not the same.

Finally, it is not clear how the shortage cost λ is determined. It is a user input but, if it is obtained from the MDF, then its units would be \$/requisition-year. Thus, it would have the incorrect units to be used in either the RISK formula or the ATVC equation used in FCIM. The units for λ for the ATVC equation must be \$/unit and the units for λ for the FCIM RISK formula must be \$/requisition.

The iterative procedure for solving for optimal Q and R described in the User's

Manual in Appendix B is not part of the current UICP model. However, that fact should have little impact on the subsequent computational comparison between the Best Value model and the FCIM model in the next section.

The Best Value model also doesn't include the Current Material Requirement (CMR) which the FCIM model explains as the "new" cost to buy the quantity already being processed by the contracting shop but which has not been awarded to any vendor. It is a one time cost. The current cost to buy based on the value in the MDF is not considered so the savings from switching to a new vendor is not determined. Thus, the reason for including this cost in the Total Relevant Costs summation is not obvious.

Two other cost terms are included in the FCIM model's total relevant costs summation. These are called the Optimal Lot Size Opportunity Cost and Lead Time Demand Opportunity Cost. The formulas imply that these are annual costs or savings. Basic to each is something called an Investment Rate (annual, apparently). No guidance is given as to what value it might have and why it might be different for the two costs (or savings). Time value of money is apparently what is intended. For the Lot Size cost there is a difference between OLS (optimal lot size) and EOQ (Economic Lot Size). When the definitions of each are examined on page I-1-2 of the FCIM User's Manual the difference is merely the negative of the Current Material Requirement (CMR). It is then multiplied by the investment opportunity cost per unit to get some sort of annual cost savings. How an annual costs savings can be argued for a one time buy of CMR is not obvious.

The lead time opportunity cost savings first computes the difference between the

new procurement lead time for the vendor under consideration and the current value of procurement lead time in the MDF. The “saving” in mean lead time demand is then computed and multiplied by the per unit opportunity cost. This cost savings appears to be considering the difference between the current and the new vendor reorder points. The savings does not, however, consider the savings in safety stock which will also result. It is apparently an attempt to value the reduction in the Stock Fund Corpus as a consequence of a reduced reorder point. However, that savings is really a one time savings. As a consequence, the Best Value model does not include it in a summation with the annual total variable costs like the FCIM model does. In conclusion, the additional “annual” costs in the total relevant costs equation are questionable and will not be considered further here.

The problem with the units of λ in the backorders term of the total annual variable costs in the FCIM model RISK formula will be considered next. Then, in the following section, a numerical comparison of the sensitivity of the FCIM and the UICP/Best Value models’ annual total variable costs to changes in procurement lead time will be made.

B. DETERMINATION OF λ FOR FCIM

In the study of the impact of procurement lead time on the selection of a vendor, the components of the total variable cost equations for the Best Value model (BV) and FCIM models are:

$$\begin{aligned} \text{BV: } & \text{IC}\{R - D_{LT} + B(Q, R)\} + \frac{\lambda E}{S} B(Q, R); \\ \text{FCIM: } & \text{IC}\{R - D_{LT}\} + \frac{4\lambda D}{Q} E(LTD > R). \end{aligned}$$

It is assumed that the reorder points are equal¹, then the $IC\{RL-D_{LT}\}$ terms can be ignored for comparison purposes. In addition, it will also be true that the optimal RISK equations will then be equal; that is,

$$\frac{SIC}{SIC + \lambda_u E} = \frac{QIC}{4W\lambda_f};$$

where:

λ_u = UICP value for λ ; and

λ_f = FCIM RISK value for λ .

Note that λ_u cannot be equal to λ_f because they have different measurement units.

Now the UICP's RISK formula can be rewritten as

$$\frac{QIC}{QIC + \lambda_u WE},$$

since $W = \frac{Q}{S}$, where S = average requisitions size (number of units/requisition). Setting the two RISK equations equal;

¹The assumption that the reorder points are equal is not unreasonable since the FCIM model is an approximation to the UICP/BV model. The FCIM model is the heuristic backorders model and the UICP/BV model is a variant of the exact backorders model presented in Chapter 4 of Hadley and Whitin (Hadley and Whitin, 1963). The exact model of Hadley and Whitin includes both a backorders per year and a time-weighted backorders per year cost term. The reason the UICP/BV model is called a variant is that it does not include the backorders per year cost term.

$$\frac{QIC}{QIC + \lambda_u WE} = \frac{QIC}{4W\lambda_f},$$

and solving for λ_f gives:

$$\lambda_f = \frac{QIC + \lambda_u WE}{4W}.$$

This λ_f has units of requisitions/year so it needs to be multiplied by S to get λ_{ATVC} , the λ value for the shortage cost term from the ATVC equation which was shown above. The result is

$$\lambda_{ATVC} = \frac{QIC + \lambda_u WE}{4Q}.$$

The units of λ_{ATVC} are \$/unit which are the correct units for computing ATVC.

The example sensitivity analysis and comparison in the next section uses an assumed value for λ_u that might have been obtained from the MDF and computes λ_{ATVC} using this formula.

C. NUMERICAL COMPARISON OF THE MODELS

For this comparison, the parameters A, I, and C will be assumed to be the same for both models. The procurement lead time LT will be assumed to be a constant of known value and will be the same for both models. The probability distribution for quarterly

demand during lead time will be assumed to be Normally distributed with a mean of D and a standard deviation of σ_D and will be the same for both models. Therefore, demand during lead time will be Normally distributed with a mean (LTD) of the product D and LT and its standard deviation can be computed using the following formula:

$$\sigma_{LTD} = \sigma_D \sqrt{LT}$$

Note that this formula is not the same as the one used in the Best Value model. That is because is not assumed here that this Normal distribution is the limiting case of a Poisson distribution.

The values of the various parameters will be:

$$Q = 20 \text{ units}$$

$$D = 10 \text{ units/qtr.}$$

$$\sigma_D = 3 \text{ units/qtr.}$$

$$S = 1.5 \text{ units/requisition}$$

$$C = \$500/\text{unit}$$

$$I = 0.23 \text{ per year}$$

$$\lambda_u = \$300 \text{ per requisition backordered/year} \quad E = 1.0$$

$$LT = 3 \text{ quarters.}$$

The analysis will consider $LT = 0, 3, 6, 9, 12$, and 15 quarters. The example steps shown below are for $LT = 3$. A summary of the results for LT values is presented in Table 2 at the end of the example computations.

The mean of the distribution of lead time demand is $D_{LT} = D * LT = 30$ for $LT = 3$.

The value of the standard deviation is $\sigma_{LTD} = \sigma_D \sqrt{LT} = 5.20$. The average quarterly requisition frequency is $W = \frac{D}{S} = \frac{10}{1.5} = 6.67$ requisitions/qtr.

The UICP optimal RISK value is

$$RISK = \frac{SIC}{SIC + \lambda E} = \frac{(1.5)(0.23)(500)}{(1.5)(0.23)(500) + (300)(1)} = 0.3651.$$

The value of the associated Normal deviate, z , is therefore 0.345. The reorder point value is then

$$R = D_{LT} + z\sigma_{LTD} = 31.8.$$

The FCIM shortage cost is computed next.

$$\lambda_{ATT} = \frac{QIC + \lambda_u WE}{4Q} = \frac{(20)(0.23)(500) + (300)(6.67)(1)}{(4)(20)} = \$53.76/unit.$$

The FCIM shortage cost term value depend on $E(LTD > R)$. The equation for $E(LTD > R)$ for demand being Normally distributed is

$$E(LTD > R) = \sigma_{LTD} \{ f(z) - z(RISK) \}$$

where $f(z)$ is the standardized Normal density function value for z . When $L=3$

$$E(LTD > R) = 5.20 \{ 0.3759 - 0.345(0.3651) \} = 1.30 \text{ units.}$$

The equation for $B(Q, R)$, from Chapter III, is

$$B(Q, R) = \frac{\beta(R) - \beta(R + Q)}{Q} \approx \frac{\beta(R)}{Q},$$

where

$$\beta(R) = \frac{1}{2}(\sigma_{LTD}^2 + (R - D_{LT})^2)RISK - \frac{\sigma_{LTD}}{2}(R - D_{LT})f(z).$$

When LT = 3,

$$\beta(R) = \frac{1}{2}((5.20)^2 + (1.8)^2)0.3651 - \frac{5.20}{2}(1.8)0.3759 = 3.768.$$

$$\text{And } B(Q, R) = \frac{3.768}{20} = 0.188 \text{ units/year.}$$

The FCIM shortage cost term value for LT = 3 is

$$\frac{\lambda_{ATV} 4D}{Q} E(LTD > R) = \frac{53.76(40)}{20} 1.30 = \$139.78/yr.$$

The Best Value model "shortage" cost term for LT = 3 is

$$(IC + \frac{\lambda_u E}{S})B(Q, R) = ((0.23)(500) + \frac{(300)(1)}{1.5})0.188 = \$59.22/yr.$$

The results for all LT values are summarized in Table 2 and Figure 1 below.

LT	FCIM	BV
0	0	0
3	\$139.78/yr.	\$59.22/yr.
6	197.84	117.49
9	241.92	177.98
12	279.55	237.20
15	311.81	295.79

Table 2. Comparison of Shortage Cost Terms from the Average Annual Total Variable Cost Equations.

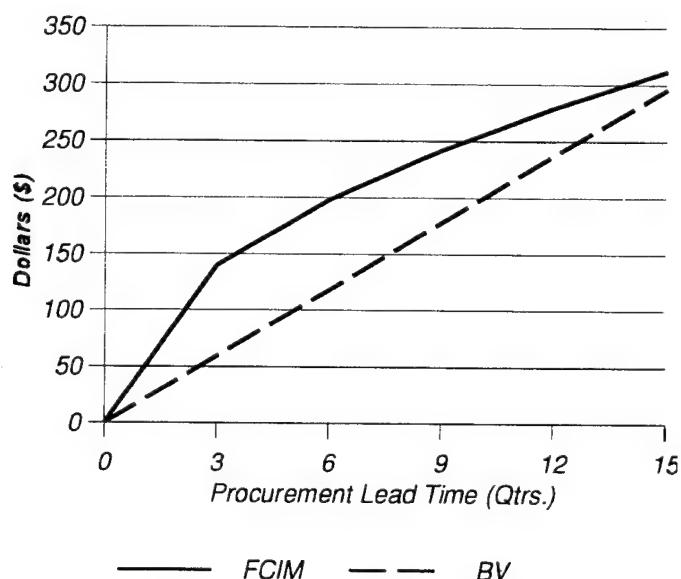


Figure 1. Shortage Cost Terms Comparison.

Note that Figure 1 displays the FCIM curve as piece-wise linear due to the graphic software. In reality, it is smooth.

Comparing the behavior of the shortage costs terms in Figure 1 and the computational steps leading to them, it becomes clear that the FCIM cost term can be

written as $K\sqrt{LT}$, where the constant $K = \frac{\lambda_{ATV} 4D^2}{Q} (f(z) - z(RISK))$. However, the BV cost term is essentially linear in LT. Thus, at very low values of LT the FCIM shortage cost term is reduced at a faster rate than the BV shortage cost term when LT is reduced, while at large values of LT it is reduced at a slower rate than the BV.

D. CONCLUSIONS

The FCIM and BV shortage costs terms behave much differently as a function of procurement lead time. The BV is approximately linear in LT whereas the FCIM model is a function of \sqrt{LT} . Thus, no general claim that one is consistently more sensitive to changes in LT can be made.

A problem does exist with the FCIM shortage cost parameter. In the FCIM total variable costs equation it has different dimensional units than the parameter provided by the MDF and used in the UICP and BV models. An attempt was made in this chapter to derive an approximate value for the corresponding FCIM shortage cost parameter if the UICP shortage cost parameter value is known.

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

This thesis was written in response to a request from the RAMP Program Office to modify an existing PC-based spreadsheet model called the Best Value model. This model was developed to measure the impact of not only item unit cost but also various procurement lead times on expected total annual variable inventory management costs in the evaluation of vendors' bids. This model was developed and is described in a 1993 Master's thesis from the Naval Postgraduate School (Horsley, 1993). It is highly iterative because it seeks both an optimal lot size (Q) and optimal reorder point (R). The RAMP focus has shifted since then to one of comparing vendors expected total annual variable costs on the premise of a given lot size (Q). Other potential users (the Navy's ICPs) also requested that the spreadsheet program be more user friendly.

Chapters I, II, and III motivated the thesis effort, presented the derivation of the old model and the modifications to it which are implemented in the new computer spreadsheet model. In addition, illustrative examples are presented to complete the understanding of the mechanics of the mathematical computations. Chapter III also addresses the customer requested modifications to the Best Value model which include the ability to use some probability distribution for expected procurement lead time demand quantities larger than 50 units and the ability to use MDF information in the computations of the model. Chapter IV provides the User's Manual. Chapter V is a comparison

between the current FCIM model and the Best Value model. It details the FCIM model and compares it with the Best Value model in a sensitivity analysis with respect to procurement lead time.

B. RESULTS AND CONCLUSIONS

1. Spreadsheet Program

EXCEL 5.0 can be easily used as a spreadsheet program to operate the modified Best Value model. Up to three vendors can be compared on one spreadsheet with the output sheet including both the input data and the expected total annual variable costs which would result from each vendor bid.

2. Normal distribution

The Normal distribution was incorporated into the Best Value model and is automatically used when expected procurement lead time demand quantities are greater than 30 units. For less than or equal to 30 units the Poisson distribution is automatically used. The Normal is a very good approximation to the Poisson for large expected demand values.

3. Incorporation of Master Data File (MDF) Information

The new spreadsheet program allows the user to enter MDF information and compute the ICP optimal target risk from that information instead of assigning some arbitrary value for target risk.

4. Comparison of the FCIM and Best Value Models

The FCIM and Best Value model shortage costs terms behave much differently as

a function of procurement lead time. The Best Value model is approximately linear in LT (procurement lead time) whereas the FCIM model is a function of \sqrt{LT} . No general claim that one is consistently more sensitive to changes in LT can be made. A problem was discovered in that the FCIM shortage costs consider only the expected number of backorders per year while the Best Value model uses only a time-weighted backorders cost term. The shortage cost parameter (λ) in the FCIM model also has different dimensional units than the shortage cost parameter contained in the MDF. A formula was derived which could be used to compute the FCIM shortage cost parameter from the MDF parameter value.

C. RECOMMENDATIONS

1. Implementation of Spreadsheet Program in the Navy

The Best Value model spreadsheet program should be reviewed at the user level and validated by the potential users from the Naval Supply Systems Command (NAVSUP) before implementation. In addition, a program needs to be designed that would integrate directly with the MDF database thus eliminating the need for the user to enter this data manually.

2. Analysis of the FCIM Model

The discrepancies identified in the FCIM model are sufficient that the model's use should be discontinued until they are corrected.

3. User's Manual

The User's Manual is intended to be used as a foundation for the use of the Best

Value Model spreadsheet. However, each organization which uses this PC-based program should write its own user's manual citing specific reports from which the required input information can be drawn.

4. Expansion to Repairable Items

The Best Value model is strictly for consumable type items. However, the Navy users will be also considering repairable items. Therefore, a repairable version of the model needs to be developed. Development of a new repairable model for ICPs is almost completed at the Naval Postgraduate School. That model could easily provide the basis for a repairable version of the Best Value model.

5. Implementation of the Best Value model by DLA

This model would also be of use to the Defense Logistics Agency (DLA) as they begin to manage the consumable item inventories of the Navy and other services. This model is ideally suited to compare various vendor's bids for the manufacture of consumable type items.

APPENDIX A. BID EVALUATION WORKSHEET

Item Nomenclature: _____

Item NIIN: _____

Quarterly Demand (quarters) _____

Contract Award Price _____

Delivery Order Cost _____

Essentially Code _____

Average Units/Requisition _____

Quantity Requested _____

Target Risk Company 1 _____

Target Risk Company 2 _____

Target Risk Company 3 _____

Company 1 Name _____

Item Cost _____

Procurement Lead time (quarters) _____

Company 2 Name _____

Item Cost _____

Procurement Lead time (quarters) _____

Company 3 Name _____

Item Cost _____

Procurement Lead time (quarters) _____

Risk Calculation Information

Item Cog _____

Shortage Cost _____

Maximum Risk _____

Shortage Cost _____

APPENDIX B. SPREADSHEET INPUT SECTION

BEST VALUE MODEL SPREADSHEET						
Input Data		Best Value Model Calculations				
Item Nomenclature	Bolt	Calculated Risk		Target Risk		
Item NIN	00-999-9898	1	Item cost	200	target risk	
Quarterly Demand	1	Shortage cost	1000	target risk		
Contract Award Price	200.00	Maximum risk	0.35	target risk		
Delivery Order Cost	50.00	Minimum risk	0.1	target risk		
Essentiality Code	1	Calculated risk	0.0440	target risk		
Average Units/Requisition	1	Risk calculated from target risk or MDF info:				
Quantity Requested	4	Risk calculated from target risk or MDF info:				
Target Risk Company 1	0.25	Risk calculated from target risk or MDF info:				
Target Risk Company 2	0.25	Risk calculated from target risk or MDF info:				
Target Risk Company 3	0.25	Risk calculated from target risk or MDF info:				
Company 1 Name		Company 2 Name	Bill's Machine	Company 3 Name	Gap Machine	
Item Cost	425.00	Item Cost	400.00	Item Cost	350.00	
Proc. Lead time	4.00	Proc. Lead time	4.00	Proc. Lead time	5.00	
Ordering Costs	250.00	Ordering Costs	250.00	Ordering Costs	250.00	
Holding Costs	350.09	Holding Costs	329.50	Holding Costs	290.88	
Backorder Costs	23.91	Backorder Costs	22.50	Backorder Costs	27.40	
Procurement Costs	1700.00	Procurement Costs	1600.00	Procurement Costs	1400.00	
Total Annual Costs	2324.00	Total Annual Costs	2202.00	Total Annual Costs	1968.28	
Target Risk Company 1	0.25	Target Risk Company 2	0.25	Target Risk Company 3	0.25	
Risk calculated from:	target risk	Risk calculated from:	target risk	Risk calculated from:	target risk	

APPENDIX C. SPREADSHEET OUTPUT SECTION

Output Section	
Input Data	
Item Nomenclature	Bolt
Item NIN	00-999-9898
Quarterly Demand	1
Contract Award Price	200.00
Delivery Order Cost	50.00
Essentiality Code	1
Average Units/Requisition	1
Quantity Requested	4
Target Risk Company 1	0.25
Target Risk Company 2	0.25
Target Risk Company 3	0.25
Company 1 Name	Acme Corp.
Item Cost	425.00
Proc. Lead time	4.00
Ordering Costs	250.00
Holding Costs	350.09
Backorder Costs	23.91
Procurement Costs	1700.00
Total Annual Costs	2324.00
Target Risk Company 1	0.25
Risk calculated from:	target risk
Company 2 Name	Bill's Machine
Item Cost	400.00
Proc. Lead time	4.00
Ordering Costs	250.00
Holding Costs	329.50
Backorder Costs	22.50
Procurement Costs	1600.00
Total Annual Costs	2202.00
Target Risk Company 2	0.25
Risk calculated from:	target risk
Company 3 Name	Gap Machine
Item Cost	350.00
Proc. Lead time	5.00
Ordering Costs	250.00
Holding Costs	290.88
Backorder Costs	27.40
Procurement Costs	1400.00
Total Annual Costs	1968.28
Target Risk Company 3	0.25
Risk calculated from:	target risk

APPENDIX D. TYPICAL ICP COG SHEET FROM SPCC

DO1/PD82											
COG		MAX RISK.		SHORT COST		PROB BP		RL CNST		MAX QTRSL	
COG		RISK.		COST		BP		CNST		QTRSL	
DPLT	0.01	0.99	0.03	20	0	20	0	20	0	20	0
1H	0.10	0.99	-400.00	20	0	20	0	20	0	20	0
1H4A	0.10	0.35	1,000.00	0	1	20	1H4B	0.10	0.40	750.00	0
1H3A	0.10	0.35	1,000.00	0	1	20	1H3B	0.10	0.40	750.00	0
1H2A	0.10	0.35	1,000.00	0	1	20	1H2B	0.10	0.40	750.00	0
1H1A	0.10	0.35	1,000.00	0	1	20	1H1B	0.10	0.40	750.00	0
1H0A	0.10	0.35	1,000.00	0	1	20	1H0B	0.10	0.40	750.00	0
1H4D	0.10	0.35	1,000.00	0	1	20	1H4E	0.10	0.40	750.00	0
1H3D	0.10	0.35	1,000.00	0	1	20	1H3E	0.10	0.40	750.00	0
1H2D	0.10	0.35	1,000.00	0	1	20	1H2E	0.10	0.40	750.00	0
1H1D	0.10	0.35	1,000.00	0	1	20	1H1E	0.10	0.40	750.00	0
1H0D	0.10	0.35	1,000.00	0	1	20	1H0E	0.10	0.40	750.00	0
1H1N1	0.10	0.35	1,500.00	0	1	20	1H51	0.10	0.35	2,500.00	0
1H1N2	0.10	0.35	1,500.00	0	1	20	1H52	0.10	0.35	2,500.00	0
1H1N3	0.10	0.35	1,500.00	0	1	20	1H53	0.10	0.35	2,500.00	0
1H1HP	0.50	0.50	0.03	0	1	0					
1H2HP	0.50	0.50	0.03	0	1	0					
1H3HP	0.50	0.50	0.03	0	1	0					
1H4HP	0.50	0.50	0.03	0	1	0					
1H1Q	0.10	0.99	-400.00	20	0	20	1H1Q	0.10	0.99	400.00	20
1H0Q	0.10	0.99	-400.00	20	0	20	1H0Q	0.10	0.99	400.00	20
3H4A	0.10	0.99	-400.00	20	0	20	3H4B	0.10	0.40	750.00	0
3H3A	0.10	0.35	1,000.00	0	1	20	3H3B	0.10	0.40	750.00	0
3H2A	0.10	0.35	1,000.00	0	1	20	3H2B	0.10	0.40	750.00	0
3H1A	0.10	0.35	1,000.00	0	1	20	3H1B	0.10	0.40	750.00	0
3H0A	0.10	0.35	1,000.00	0	1	20	3H0B	0.10	0.40	750.00	0
3H4D	0.10	0.35	1,000.00	0	1	20	3H4E	0.10	0.40	750.00	0
3H3D	0.10	0.35	1,000.00	0	1	20	3H3E	0.10	0.40	750.00	0
3H2D	0.10	0.35	1,000.00	0	1	20	3H2E	0.10	0.40	750.00	0
3H1D	0.10	0.35	1,000.00	0	1	20	3H1E	0.10	0.40	750.00	0
3H0D	0.10	0.35	1,000.00	0	1	20	3H0E	0.10	0.40	750.00	0
3H1N1	0.10	0.35	1,500.00	0	1	20	3H51	0.10	0.35	2,500.00	0
3H1N2	0.10	0.35	1,500.00	0	1	20	3H52	0.10	0.35	2,500.00	0
3H1N3	0.10	0.35	1,500.00	0	1	20	3H53	0.10	0.35	2,500.00	0
3H1HP	0.50	0.50	0.03	0	1	0					
3H2HP	0.50	0.50	0.03	0	1	0					
3H3HP	0.50	0.50	0.03	0	1	0					
3H4HP	0.50	0.50	0.03	0	1	0					
3H1Q	0.10	0.99	-400.00	20	0	20	3H1Q	0.10	0.99	400.00	20
3H0Q	0.10	0.99	-400.00	20	0	20	3H0Q	0.10	0.99	400.00	20

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